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Simulation as a Tool for Research

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Simulation as a Tool for Research

Simulation Methodology

With the emergence of very large, very complex man-machine systems there is an increasing need for new and improved scientific techniques for their study. One such means is through a facility like the Systems Simulation Research Laboratory (SSRL). Here, with the aid of an electronic computer and the capabilities of simulating complex systems with people in the feedback loops, we can conceive of breaking free of traditional constraints. We are not limited to the measurement of significant variation in isolated variables between control and experimental groups. We take the variables as they come, including many we have no means of identifying, and proceed to study the total system.

Of course, we are faced with many problems: How to get at significant variations? What are the relevant variables? Which are the important criteria? How much improvement is "real"? How much is due to sampling variation? How reliable is the simulation? How valid is the simulation?

These are some of the questions for which we hope to get at least partial answers through our research in SSRL in the coming years.

In the past, the most respected scientific technique was that of analysis -- wherein a problem would be broken down into the smallest possible parts that could be studied in a laboratory. Now, along with the growing interest in large systems is the increasing concern with the functioning of the system as a whole. To attack this problem has required new tools and facilities. A powerful new research procedure consists of systems simulated in the laboratory in real time, exploiting the capabilities of modern electronic computers, and including people in the feedback loops.

The advantages of simulation as a research tool in the study of complex systems is evident: the real system in the field is not as amenable to control as a simulation of it; there is no interruption of the on-going activities in order to conduct the research; productive research requires the taking of quantitative measurements, which again can better be accomplished in a simulation study than by observation of the actual system. These primary advantages are really the advantages of the laboratory over the field.

There are still additional advantages of simulation as a research technique:

- (1) It can compress or expand real time.
- (2) It provides the ability to experiment, test, and evaluate new systems or proposed changes to existing systems in advance of having to make firm commitments.

- (3) It makes for more economical experimentation, both in time and money.
- (4) It permits the replication of experiments under different conditions.

But what, exactly, do we mean by simulation? This is not an easy question. There are many and sundry definitions, and a variety of applications. At SDC we use the concept of "simulation" probably in a wider scope than that employed in any single field of inquiry. We are exploring the utility of simulation in arriving at optimal solutions to management control problems, we are using the simulation of an environment for the very large scale training of air defense forces, and we are simulating a school system in our new laboratory to investigate the feasibility of automation in this field -- just to note a few examples.

Simulation Types

To provide a frame of reference we might consider various forms of simulation ordered along a single continuum on the basis of degree of abstraction, i.e., the extent to which the simulation model is abstracted from the real-life system, operation, or procedure. On such a scale we can designate five reference points:

- (1) Identity simulation
- (2) Replication simulation
- (3) Laboratory simulation
- (4) Computer simulation
- (5) Analytical simulation.

1. Identity simulation. - At the one extreme, the real system itself can be used as the "model" to gain knowledge about itself. However direct and simple it might sound, it is usually neither practical nor feasible to determine the inherent properties of a system by observing its operations. Limited time and resources often force the use of shorter, less expensive methods than the "identity simulation."

2. Replication simulation. - Only one step removed from the real-life instance is the attempt to replicate it with the highest degree of fidelity, by means of an operational model of the system in its normal environment. Such "replication simulation" really involves very little abstraction from reality, and also provides very little gain; except to make possible the limited study of selected dangerous or future situations. A subcategory of this classification might involve essential replication of operational gear while employing abstracted inputs. A case in point is the Air Defense Command's System Training Program.

3. Laboratory simulation. - Next, along the continuum, the replication might be attempted in the laboratory instead of in the field. Here it is necessary to choose the relevant features of the real system for representation in the laboratory, and also to decide on the means of such representation. A system may be made up of such diverse elements as people, hardware, operating procedures, mathematical functions, and probability distributions. A laboratory model might consist of the actual replication of some elements and the abstraction and substitution by symbolic representation of others. A wide range of simulation types is encompassed by "laboratory simulation," and perhaps is best exemplified by operational gaming.

4. Computer simulation. - Another degree of abstraction from the real system leads to the complete "computer simulation." This is the classical meaning of "simulation" in operations research. All aspects of the system are reduced to logical decision rules and operations which can be programmed for a computer. It might be said that if the human decision makers are the real components of the system then the flow diagrams provide the simulation bridge to the decision algorithms, which are the artificial components.

5. Analytical simulation. - The highest degree of abstraction would involve a complete representation of the real system by means of a mathematical model, and a solution (at least theoretically) can be obtained by analytical means. While this sounds like an ideal approach, it may be neither practical nor desirable to strive for a complete mathematical representation. Such a thorough mathematical description could easily exceed the capacities of the professional staff and of the computing equipment, or it could require an inordinate amount of time for accomplishment.

The least and the highest degrees of abstraction -- "identity simulation" and complete "analytical simulation" -- may not be of much experimental value, but they do provide useful conceptual bounds for the simulation continuum.

Examples from Air Defense and Business

To assist in delineating the five forms of simulation, let us conjure up examples of each type, and let us try this in the areas of air defense and business. The identity simulation is, of course, an obvious concept and would be an actual war in the military example. Replication simulation could be effected by means of a SAC mission flown to test the air defenses of the United States: enemy bombers would be replaced by SAC bombers; ADC would exercise all of its operations, but actually fire no weapons. Laboratory simulation in air defense was planned and conducted by SDC for a number of years in what we called "Indoctrination Direction Centers." An Air Defense site was simulated in a laboratory with real radar scopes and human operators, but using computer generated radar returns and a special simulator to dynamically represent fighter interceptors in response to the controller's decisions in the system. A variant of this laboratory simulation is the System Training

Program employed throughout the United States, Canada, Alaska, and parts of Europe. Still considering the air defense field, an example of computer simulation is the "Air Battle Model," originally created by RAND and now operated by OMEGA (Operations Model Evaluation Group, Air Force). This computer model consists of a detailed simulation of the operations of both sides in an air battle, and several hours of play represent the equivalent of several days of strategic air war. The ultimate in abstraction would be a mathematical game-theoretic approach to war.

Now, let us consider what the continuum of simulation types might look like in the field of industry or business. Obviously, the identity simulation is the business operation itself. Examples of replication simulation include pilot plant operations and operations research endeavors at reallocation of parts of a production line. For laboratory simulation there are the very popular business games, with which most of you are probably acquainted. A quite different example of laboratory simulation recently was reported in Business Week*. At the Enrico Fermi Atomic Power Plant near Detroit, a simulated (analog) operation of the plant is employed in training operators in the nuclear reaction system. We tend to classify this as laboratory simulation because, in addition to the computer simulation of the operation of the plant, human beings manipulate the model and are part of it. On the other hand, in a complete computer simulation the human interactions also are reduced to decision algorithms. An example of the latter is the Management Control System study developed at SDC, in which a hypothetical business operation (performing some 200 separate tasks, and including inventory, sales, personnel and budget considerations) is completely simulated in a computer. Finally, for analytical simulation an example can be taken from the petroleum industry. Linear programming is the principal mathematical technique used to determine the optimal fractionation ratios for the "crude" as a function of the current market prices for the various derivatives.

SDC Simulation Projects

The foregoing discussion of simulation was intended to provide a framework for much of the systems research effort at SDC. More detailed descriptions of the use of simulation as a tool in research will be brought out in the ensuing briefings. The six reports cover a wide range of the simulation continuum. In the first of these -- the study of human data-processing behavior -- we have a clear example of "laboratory simulation". The second report, SIMPAC, just as clearly falls into "computer simulation". The Leviathan studies are not so easily categorized: Phase I definitely belongs in "computer simulation," but the second phase of Dr. Rome's work will be recognized as "laboratory simulation." The decision-making study to be reported by Dr. Shure again is of the "laboratory" variety. The research in CLASS can most appropriately be designated as "replication simulation," although it also has the "laboratory

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flavor." Finally, the Terminal Air Traffic Control study was expressly designed as the first major "laboratory simulation" model for SSRL.

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You can see that our emphasis is on the category "laboratory simulation," and that is as it should be because of the unique capabilities offered by SSRL. Nonetheless, in our research on man-machine dynamics, we shall sample all along the simulation continuum -- from the pure mathematics and independent computer operations to every conceivable mixture of computer-laboratory simulation.

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System Development Corporation,
Santa Monica, California
SIMULATION AS A TOOL FOR RESEARCH.
Scientific rept., SP-565, by
H. H. Harman, 25 September 1961, 5p.
Unclassified report

DESCRIPTORS: Simulation.

Reports an increasing need for new
and improved scientific techniques
for the study of man-machine systems.
Describes the advantages of SDC's
SSRL (Systems Simulation Research
Laboratory) in investigating the use

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of simulation as a research tool.
Defines the various types of
simulation: identity simulation,
replication simulation, laboratory
simulation, computer simulation,
analytical simulation. Presents
examples from air defense and
business.

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